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10 Gb/s Real-Time All-VCSEL Low Complexity Coherent scheme for PONs

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Abstract: Real time demodulation of a 10 Gb/s all-VCSEL based coherent PON link with a simplified coherent receiver scheme is demonstrated. Receiver sensitivity of -33 dBm is achieved providing high splitting ratio and link reach.

OCIS codes: (060.2330) Fiber optics communications; (140.7260) Vertical cavity surface emitting lasers; (060.1660) Coherent communications

1. Introduction

The demand for high-speed access networks is continuously growing. This demand is driven by new applications that require higher bandwidth. Applications such as youtube, Netflix etc. are becoming the preferable form of video entertainment offering [1]. Typically, fiber-to-the-home (FTTH) networks are based on passive optical networks (PONs). WDM-PON is the leading candidate technology for next generation access networks beyond 10 Gb/s [2]. The main for WDM-PON is cost efficiency. Therefore, several assumptions have to be taken: colorless ONUs, single fiber operation for upstream and downstream, no use of external modulators and no use of optical amplifiers [3].

It is well known that coherent detection has many advantages such as increasing sensitivity, extending reach, increasing network capacity by close wavelength allocation, allowing for dispersion compensation or demodulation of advanced modulation formats. Although, the main remaining challenge of coherent PONs is cost reduction in order to make it comparable with typical direct detection systems. Coherent detection has been typically associated with high quality lasers and complex receivers with digital signal processing not suitable for cost effective PON.

Vertical cavity surface emitting lasers (VCSELs) are gaining attention in access networks due to lower manufacturing cost and lower power consumption than edge-emitter lasers [4].

Previously, in [5] we have demonstrated coherent detection using VCSELs for signals as well as LO. In this case, however, the system only operated at 5 Gb/s and digital sampling at 20 GSa/s was required for the demodulation. The latter is problematic in PON scenarios due to cost issues. In this paper we present, for the first time to our knowledge, an all VCSEL coherent PON system employing real-time detection with no use of digital signal processing. Additionally, the bit rate of the system has been doubled to 10 Gb/s. This demonstration of a real-time 10 Gb/s all VCSEL, no DSP coherent PON represents the lowest cost and complexity coherent system ever reported for PON scenarios. The only added equipment when compared with conventional direct detection is a VCSEL, 3 dB fiber coupler, 6 dB electrical splitter and an XOR gate.

The optical transmitters and the LO are photonic bandgap GaInNAs VCSEL TOSAs from Alight Technologies Aps. Direct modulation at 10 Gb/s amplitude shift-keying (ASK) over 25 km SMF was performed. Free running and un-cooled VCSEL operation were used for the transmitters as well as for the local oscillator.

2. Experimental Setup

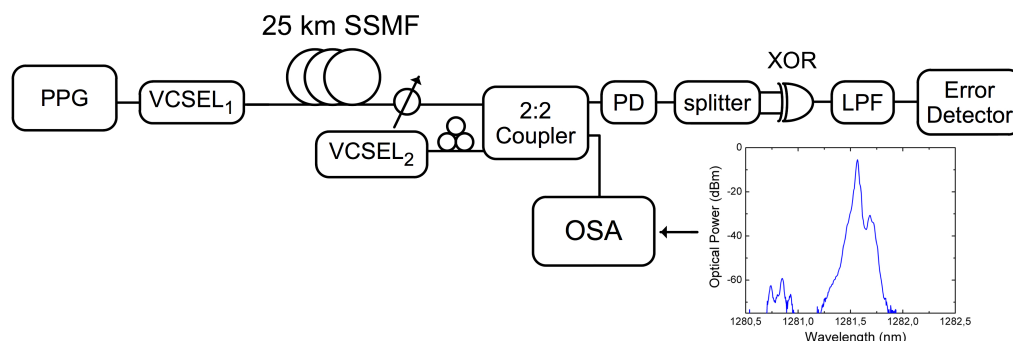


Figure 1. Setup. Pulse pattern generator (PPG), Photodetector (PD), Variable optical attenuator (VOA), Low pass filter (LPF)

Figure 1 shows the experimental setup. A pulse pattern generators directly modulate a 1.3 μm VCSEL. Single drive configuration is used for the VCSEL. The measured wavelength of the VCSEL is 1281.68 nm. The VCSEL is free-running with no cooling or temperature control. The signal is transmitted through 25 km of standard single mode fiber (SSMF) with no optical amplification. Fiber launch power of the VCSEL into the fiber is -1 dBm. At the coherent receiver input, a variable optical attenuator (VOA) is used to assess BER vs. receiver input power and to emulate the loss of a passive PON splitter.

Coherent Receiver:

Due to the low chromatic dispersion in the spectral region of 1.3 μm , dispersion compensation can be omitted, and the in-phase and quadrature components of the signal are not required for signal demodulation. Therefore, for amplitude modulation, the coherent receiver scheme can be simplified from a conventional 90 degree hybrid scheme with two photodiodes and digital signal processing [6], to a simpler one composed of a 3 dB coupler, a single photodiode and an analogue envelope detector [5]. The LO is a free running, un-cooled and continuous-wave VCSEL with a polarization controller to maximize the output at the photodiode. Bias of the LO VCSEL is used for wavelength for intradyne coherent detection. Embedded graph in Fig.1 shows the combined spectrum of the received signal and the LO.

The envelope detector is composed of a 6 dB electrical splitter, an XOR gate and a low pass filter. The outputs of the 6 dB electrical splitter are connected to the inputs of the XOR gate with phase-matched RF cables. The XOR gate is not used for its typical digital behavior but for its analogue behavior instead to rectify the signal. Figure 2 shows the signals in each step of the envelope detection. The sensitivity of the XOR is approximately 20 mV. When a logical '0' is transmitted, the amplitude level at the output of the photodiode is lower than the XOR sensitivity, and the output of the XOR gate is 0 mV. This is observed from Fig. 2.a. When a logical '1' is transmitted, the amplitude level of the signal out of the photodiode is higher than the XOR sensitivity. As matched RF cables are used between the 6 dB splitter and the XOR gate, the two input signals are equal, and the XOR gate will produce a positive signal (200 mV) at its inverted output irrespective of the sign of the signals at the input. In this way, the XOR gate is able to rectify the signal from the photodiode. This is illustrated in Fig. 2.b, where the signal after the XOR gate and a DC block is shown. The bandwidth limitation of the XOR gate removes most of the oscillation in the signal due to the frequency offset of the transmitted signal and local oscillator. Fig. 2.c shows the signal after additional low pass filtering. As can be observed, the signal now has properties similar to an NRZ-OOK signal, and can therefore be detected in real time using a standard error detector.

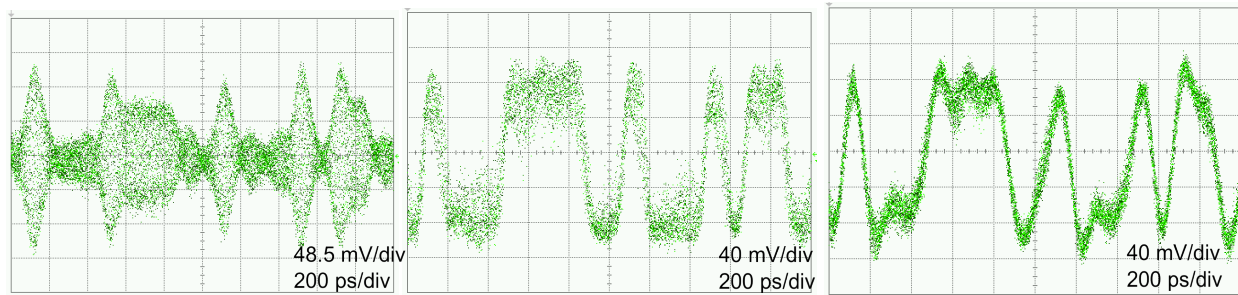


Figure 2. a) Output photodiode, b) output XOR gate, c) output low pass filter

3. Results

The experiment has been performed at 2.5 and 10 Gb/s. The system at 2.5 Gb/s is evaluated with a PIN and a balanced photodiode in order to compare the performance of the two configurations. Figure 3.a shows the bit error ratio (BER) curve after 25 km SSMF. BER below 10^{-9} is measured for received power of -26 dBm with the PIN photodiode and -31 dBm with balanced photodiode. In both cases, no error floor is observed. At the forward error correction (FEC) limit of $\text{BER} < 2.2 \times 10^{-3}$, the sensitivity is measured at -39 dBm with the balanced photodiode and -37 dBm with the PIN photodiode. In the case of FEC, 7% overhead has to be considered for the effective bit rate. Significant improvement is observed by using balanced photodiode. 5 dB gain in sensitivity at $\text{BER} < 10^{-9}$, and 2 dB sensitivity gain at $\text{BER} < 2.2 \times 10^{-3}$.

For the 10 Gb/s the performance was assessed with the 20 GHz bandwidth balanced photodiode. Fig. 3.a shows the BER curve. BER below 10^{-9} is measured at -23 dBm. At the FEC limit of $\text{BER} < 2.2 \times 10^{-3}$, the received power sensitivity is -33 dBm. Fig 3.b shows the optical back-to-back eye diagram at 10 Gb/s. Fig 3.c shows the eye

diagram of the received signal after 25 km SSMF. No pulse broadening due to chromatic dispersion is observed after fiber transmission.

A power budget calculation has been done in order to estimate the maximum splitting ratio allowed by this system with a passive splitter. Considering 9 dB attenuation of the 25 km SSMF at 1.3 μm , the power margin of the received power at the FEC limit sensitivity is 23 dB and 29 dB at 10 Gb/s and 2.5 Gb/s, respectively. These power margins correspond to a passive splitting ratio of 199 and 794 at 10 Gb/s and 2.5 Gb/s, respectively.

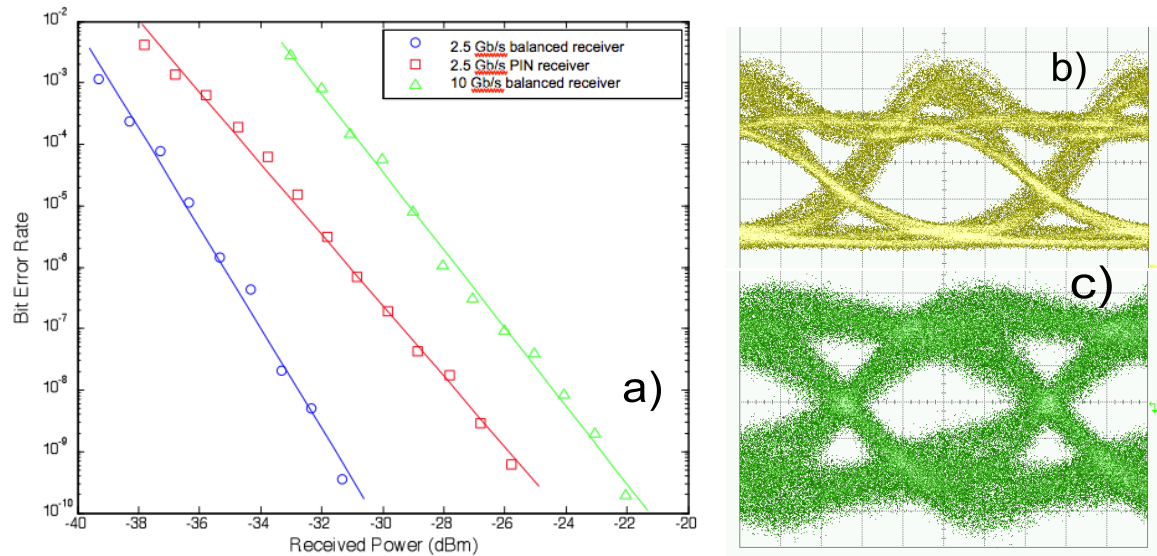


Figure 3. a) BER curves at 2.5 Gb/s and 10 Gb/s after 25 km SSMF, b) eye diagram of the optical back-to-back signal at 10 Gb/s, c) eye diagram of received signal at 10 Gb/s.

4. Conclusion

We have proposed an experimentally demonstrated for the first time an all-VCSEL coherent PON link with realtime demodulation at 10 Gb/s. Transmission after 25 km SSMF was performed with sensitivity of -33 dBm allowing for a passive splitting ratio of 199.

The potential cost reduction and good performance of our proposed approach make VCSEL-based coherent PONs a strong candidate for application in future PONs. Future work on this approach will be done adding more transmitting channels implementing a WDM system.

5. References

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